Guidelines and Methods for Mapping and Monitoring Kelp Forest Habitat in British Columbia

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Preface

This document is meant to provide readers with a basic understanding of canopy-forming kelps of coastal British Columbia, *Nereocystis luetkeana* and *Macrocystis integrifolia* and the ecology of the kelp forest habitat they form, and to provide guidelines for community groups to develop programs to map and monitor this habitat at a local level. It provides a basis for the collection of consistent and comparable data by groups spanning the coastline of this province.

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Introduction

Canopy-forming kelps play an important role in many nearshore marine ecosystems. They form extensive forests below the water's surface, providing ideal habitat that supports populations of fish, invertebrates, marine mammals and marine birds (Berry et. al, 2001). They also are a key source of carbon in coastal food webs, forming a base of carbon for secondary production (Duggins et. al, 1989). Two species of canopy-forming kelps are present on British Columbia's coast: *Nereocystis luetkeana* and *Macrocystis integrifolia*. Both range from Alaska to California, forming distinct beds as well as mixed beds.

Kelp forests are affected by a wide range of natural and anthropogenic factors. Sea urchin grazing can dramatically reduce the extent of beds, an impact that is moderated by sea otter predation on urchins (Duggins, 1980). Rises in ocean temperature can also decimate kelp beds, which raises cause for concern about the impact of sea surface temperatures associated with climate change. It has been shown that, while kelps can adjust metabolic processes in order to acclimatize to temperature changes, increased temperature negatively affects the resilience of kelp beds to additional stressors, such as storm disturbances (Wernberg et. al. 2010). El niño events impact kelp beds not only because of temperature variation, but also because of storm activity and decreased upwelling, which typically replenishes nutrients (Berry et. al, 2001). Anthropogenic impacts on kelp forests include runoff from coastal development, which can reduce water quality by introducing toxins and reducing light penetration (Steneck et. al. 2002). Boating activity can impact kelp forests by physically damaging plants with propellers. In British Columbia there is a commercial "Spawn-on-Kelp" fishery in which great kelp blades are harvested after herring deposit their roe on them. The vast majority of BC's harvest is exported to Japan. There is also a relatively small harvest of kelp as a specialty edible seaweed and for fertilizer.

Mapping and monitoring of canopy-forming kelps is an important step towards understanding natural and anthropogenic fluctuations in the areal extent and overall health of beds. *Nereocystis luetkeana*, commonly known as bull kelp, is an annual kelp, growing anew each year from spores, and thus may lose or take-hold of a given area from one year to the next. *Macrocystis integrifolia*, or great kelp, is perennial, and thus persists year-to-year and may exhibit a lower level of natural fluctuation. Monitoring will need to take into account these natural fluctuations, as well as local environmental factors such as ocean temperature, tidal currents, substrate type, bathymetry, upland development, and freshwater drainage. Developing a monitoring strategy, and a network of communities engaged in monitoring, will be very important in order to protect and maintain this crucial marine habitat.

A number of mapping and monitoring programs have been undertaken to date, but programs are not yet widespread, nor are the data compiled in a central location. The Washington State Department of Natural Resources has a monitoring program that monitors the state's coastline for *N. luetkeana* and *M. integrifolia s* beds by aerial photography on a yearly basis (WDNR, 2010). There is also a monitoring program for *Nereocystis* in Kachemak Bay, Alaska, undertaken by the Kachemak Bay Research Reserve.

A number of studies have been carried out through universities, research institutions and state departments, and thus contribute to a body of literature dedicated to an understanding of the factors underlying the biology, and ecological interactions, of kelps. Most areal extent surveys have been carried out by aerial photography rather than on-the-water survey. Aerial survey is often not likely to be a feasible way for communities to approach regular monitoring, and thus is not addressed in this manual. Widespread and detailed mapping and monitoring, on a long-term basis, will depend on the engagement of a network of community groups along BC's coast. The purpose of this manual is to guide community groups in developing and implementing mapping and monitoring programs.

Ecology of Canopy-Forming Kelps

Kelp forests are ever-changing habitats, reflecting year-to-year changes in their environment. Beds consisting of *N. luetkeana* are typically less consistent in their areal extent, as it is an annual plant that grows anew from spores each year, losing or gaining hold of particular areas. The life history of *M. integrifolia* enables it to form beds that are more consistent in location and areal extent year-to-year, as it is a perennial plant and persists over multiple years. In order to understand the natural variability in kelp forest habitats a basic overview of kelp biology and ecology is necessary. This section will discuss reproduction, environmental requirements, and ecological interactions.

Kelps, which are also known as laminariales, make up the order Phaecophyceae, or brown algae. In the life cycle of both *N. luetkeana* and *M. integrifolia* there are two major stages, referred to as heteromorphic alternation of generations. For both of these species this involves alternation between a large sporophyte stage and a microscopic gametophyte stage. The sporophyte stage is the form that is commonly observed and is the focus of mapping and monitoring activities. Its morphology, in the case of *N. luetkeana*, consists of a buoyant, carbon monoxide-filled bulb called a pneumatocyst, with a long stipe that terminates in a holdfast. The holdfast has many fingers with which it attaches to rocky substrates. Blades extend from the top of the pneumatocyst and are the plant's photosynthesizing structures. *M. integrifolia* has blades extending off of the full length of the stem, and each blade is buoyed by a small pneumatocyst. It also anchors to rocky substrates with its holdfast.

The sporophyte is the reproductive stage of the organism. *N. luetkeana* reproduces sexually, forming spore patches, or sori, on the blades of each plant. These gradually move to the end of the blades and fall off. When the sori fall off the blades they release spores, which grow into male and female gametophytes. *M. integrifolia* does not produce spore patches, but releases spores from special spore-producing blades, called sporophylls, which lack pneumatocysts and are among the first few blades on each branch (Druehl, 93).

The gametophytes are the microscopic stage of the kelp life cycle, and consist of male and female forms. Female gametophytes produce non-motile eggs, which are fertilized by sperm from the male gametophytes. Once fertilized, the egg develops into a miniature sporophyte, eventually growing to reach the surface. By summer the sporophytes have reached the surface and will soon begin to release spores again.

N. luetkeana persists well in high-energy, open coastal environments, where its holdfast allows it to withstand strong tidal currents. It requires a rocky substrate in the subtidal zone for its holdfast to attach to, and so is not found in sandy bays to any significant extent. Substrate type is an important factor that can affect its presence or extent year to year, as the movement of sand bars can cover or expose adequate substrate for it to attach to (Schoch, 2001). *M. integrifolia* also does well in areas with a high level of wave action, although it may prefer locations slightly sheltered from the full force of the open ocean. It attaches itself subtidally, as well as in the lower intertidal zone, to rocky substrates. *M. integrifolia* does not appear to grow in areas with lower salinity than the open ocean, and so is not found very far into certain channels and straits, such as the Strait of Juan de Fuca.

Kelp forests generally exist in the mid-latitudes of the globe, limited near the equator by higher ocean temperatures and near the poles by lower levels of sunlight. Studies have shown kelps, including *N. luetkeana* and *M. integrifolia*, to be sensitive to rises in ocean temperature and other conditions related to el niño fluctuations, such as decreased upwelling and increased storm activity. Upwelling is an important process that replenishes nutrient availability for kelp ecosystems. There is concern about the health of kelp forests regarding their resilience to the impacts of climate change, in particular increased ocean temperatures and storm activity. A study by Wernberg et. al. found that kelps can adjust metabolic processes to acclimatize themselves to changing ocean temperatures throughout the seasons, but that increased ocean temperatures make kelps more susceptible to additional stressors, such as storm activity. Thus, kelp forests may remain in-tact with higher ocean temperatures, but their resilience is compromised and this means that kelp abundance and distribution will likely be negatively impacted. *N. luetkeana* may also be seriously impacted by rises in atmospheric carbon dioxide levels. Furthermore, because of its massive growth rates it responds quickly to changes in the conditions of its environment and thus can be an important bio-indicator.

Kelp species have been shown by Duggins et. al. (1989) to be very important as a carbon source in coastal marine ecosystems. There is a strong connection between levels of secondary production and proximity to kelp beds, and an analysis of stable carbon isotopes confirms that kelp-derived carbon can contribute “significantly to the carbon assimilated by secondary consumers” (Duggins et. al.). Kelp forests are some of the most productive and diverse ecosystems in the world, owing largely to their high level of primary production. They form a habitat structure that provides shelter from wave action, reduces light from the surface, offers substrate for sedentary organisms and algae, and for mobile organisms specialized to feed on the inhabiting organisms of kelp blades and stems (Steneck et al, 2002). They provide a structure and carbon source for an ecosystem involving complex interactions between marine mammals, fishes, marine birds, crabs, sea urchins, mollusks, and other algae and invertebrates.

One set of interactions in particular, between kelp forests, sea urchins and sea otters, has received great attention. It was previously believed that bottom-up forcing mechanisms were the primary factors affecting populations in kelp forest ecosystems – thus, kelp populations would be affected by availability of nutrients and light, sea urchins by the availability and quality of macroalgae, and sea otters by the availability and quality of urchins. It became evident, however, that recent and dramatic shifts in relative populations of these species were the result of top-down forcing mechanisms, i.e. predation. It is now understood that the hunting of sea otters to the point of extirpation from many parts of the British Columbia-Alaska coastline was responsible for a population boom of sea urchins and a resulting decimation of kelp forests all along the coast (Estes et. al. 2004). As sea otters have returned or been translocated to portions of this coastline their predation on sea urchins has begun to control urchin populations and allow for the re-establishment of kelp forests.

Mapping and Monitoring Parameters

There are a variety of parameters that can be measured in order to study changes in kelp beds and the surrounding environment. Mapping and monitoring programs can choose which parameters they incorporate based on their goals and their capacity to collect data. This section will outline these parameters and their relevance to monitoring strategy.

Location – Knowing the locations of kelp forest habitat is the first and most basic step towards recording changes and protecting these habitats. Fisheries and Oceans Canada follows a principle of "no net loss" to the productive capacity of habitats. If the locations of kelp forest habitats are recorded then this information may be used to protect them from the impacts of developments, which must either avoid impacting the productive capacity of habitats, or provide compensation. Since *N. luetkeana* is an annual kelp, yearly reports of bed locations will help to establish knowledge of its recurring presence, and patterns of change. *M. integrifolia* persists year-to-year, therefore changes are likely to be in areal extent rather than location.

Delineation – Delineation of the boundaries of kelp beds will allow for monitoring to detect changes and patterns in the areal extent of kelp beds. For *M. integrifolia*, monitoring will track the expansion or contraction of beds, while for *N. luetkeana* it will track the areal extent to which beds are re-established each year. This information can help to detect anthropogenic impacts on kelp beds, as well as to understand natural fluctuations and the impact on kelp beds of changes in the environmental conditions. Developments and activities that can be shown to negatively impact kelp forest habitat may be obligated to alter their practices or compensate for damages caused.

Depth Measurements – *M. integrifolia* and *N. luetkeana* both anchor themselves in the subtidal zone, with *M. integrifolia* growing relatively deeper than *N. luetkeana*. Both are constrained at their lower range by light availability, and substrate type may also constrain their distribution. Thus, depth measurements may provide an indication of either substrate type or water quality. Runoff and pollution from coastal development can cause increased turbidity, decreasing the ability of kelps to photosynthesize in deep waters and decreasing their maximum depth. Yearly data regarding the maximum depth of kelp beds may provide an indicator of the changing health of the beds.

Sea Surface Temperature – Sea surface temperature is the main factor limiting the growth of kelp beds at the lower latitudes. Rising temperatures are also shown to have a negative impact on the extent of kelp beds at the mid latitudes. Kelps have been shown to respond metabolically to changes in ocean temperature, but this also results in a decreased resilience to additional stressors, such as storm activity or water pollution. Through el niño cycles, temperature covaries[1] with other conditions, such as upwelling which affects the abundance of nutrients replenished to kelp forest ecosystems. Sea surface temperature data will be helpful for observing correlations between environmental conditions and the abundance, distribution and health of kelp forest habitat.

[1] Two or more measures or qualities are observed to fluctuate together.

Methods

The following methods are based on those used by the Mayne Island Conservancy to map kelp beds off the shores of Mayne Island in August and September of 2010. They are provided here as a guideline for organizations and communities to map kelp beds in a consistent manner, using a standardized data entry form. They are designed to be carried-out on the water, using kayaks as the data collection platform and handheld GPS units to record waypoints.

Mapping and monitoring should both be carried out in the late summer or early fall, when kelp has grown to its full extent but has not yet begun to die back. This will help to maintain consistency of data collection bed-to-bed, region-to-region, and year-to-year. Also to maintain consistency across surveys it is suggested to use the criteria outlined below to distinguish between kelp areas as polygons, lines and points. This strategy allows for highly accurate representation not just of full kelp beds, but also solitary bulbs, small clusters and thin continuous strips.

Data collection during mapping and monitoring should take place only within one hour before and after low tide, when the tide height for the entire two-hour interval is below a set level. Our data were collected with a tidal height 1.2m MLLW or less. This is the tide limit for the data collected by the Washington State Department of Natural Resources in its Nearshore Habitat Kelp Monitoring program, and thus serves as an established guideline that other kelp monitoring programs can follow, in order to maintain consistency and for data comparison (Britton-Simmons). The reason for such a guideline is that the visible area of kelp beds is greatly affected by tidal stage, and even at low tide some bulbs will likely be submerged. The most reliable way to control for this variability is to include in the survey only kelp bulbs that reach the surface, and to confine surveys to a defined range of tidal height. It may be tempting to include bulbs that are clearly visible just below the surface, but then it would be necessary to control for water depth and clarity. Tidal height can reliably be accounted for with information obtained from many tide-prediction sources, including http://tbone.biol.sc.edu/tide/sites_othernorth.html.

Kelp visibility has also been shown to vary with current speed (Britton-Simmons et al., 2008). As current speeds increase they can pull individual plants to an angle, decreasing their vertical reach and eventually submerging them. The study by Britton-Simmons et al. established a strong correlation between current speed and areal extent of beds, as recorded by oblique angle photography. This is a factor that could further affect the recorded extent of beds in mapping and monitoring, but is not accounted for with the current methodology. Currents are highly variable, from the middle of a channel to the shorelines, and even between opposite edges of a kelp bed. Currents along the shoreline are often different from the current in the center of a channel, and highly localized due to variations in shoreline shape and bathymetry.[2] Thus, current charts often do not provide enough accuracy to control for current speeds. However, when possible it is still recommended to time surveys so as to minimize the impact of currents. This may be difficult in some cases, especially while maintaining the tidal height requirements. It may, however, also be a safety concern in passes where currents reach high speeds.

Specific strategies for monitoring may be developed to suit the needs, goals and capacity of the sampling group. A recommended strategy is to map the full extent of kelp beds within a geographical region, and monitor the full extent of the mapped area yearly for multiple years. Yearly monitoring is important, at least for the first few years, because *N. luetkeana* grows anew each year and thus can be expected to have a different areal extent and spatial distribution each year. In order to first observe how the kelp of a given region can fluctuate naturally year-to-year, monitoring should at first be conducted annually. After a few years of annual monitoring, groups may wish to select a more manageable number of particular beds for yearly monitoring. Monitoring sites could be selected based on areas of concern for environmental impact, with at least one site being chosen as a reference site in an area that receives relatively little impact. Sites could also be selected for monitoring by dividing the shoreline into equal-sized segments and randomly selecting a subset of them. In order to quantify the error that may derive from survey methods, groups should choose a particular kelp bed to survey three separate times throughout each survey season. This will give an approximation of the variability that can occur due to the survey criteria.

Community involvement in the mapping process can be very beneficial, both for the survey group and the community. Community members may be able to provide information about the location of kelp beds, or their historical extent and trends they have observed. They may also be enthusiastic about participating in the mapping process as volunteers. This presents an excellent opportunity to increase the capacity of an organization to carry out field work, while engaging community members in mapping and monitoring activities, and spreading awareness about issues related to kelp forests and their ecological importance.

Location

Locations of kelp forests are easily determined due to the visibility of bulbs on the water's surface. Community solicitation, aerial photos, and scouting surveys are all possible methods for determining kelp locations, but these may be unnecessary. It is likely that thorough mapping will require the entire shoreline to be surveyed, especially where kelp is fairly ubiquitous. Knowing the locations of larger beds will help for

[2] Topographic measurements of the sea floor.

purposes of planning field days efficiently, but it will not be necessary to pre-determine the locations of all beds before beginning a survey.

Bed Delineation

In order to be consistent kelp beds should be delineated when greater than 5m across. If they are less than 5m across they can be recorded as lines or points, as described below. The edge of the bed is defined as the point at which the distance between kelp bulbs becomes greater than 8m. This number was established in order to maintain consistency, by measuring the distance between bulbs that were determined, on the basis of visual observation, to be inside or outside of a bed. Bulbs separated by a distance of more than 8m are considered outside of the bed and should be recorded separately. Paddle the kayak along the contours of the bed's edge, recording waypoints every 5-10m or where the edge curves. Using the data collection sheets, mark the waypoints that correspond to each bed so that beds can easily be drawn once waypoints are input to GIS software. The waypoints are used to georeference the boundaries of kelp beds and create a polygon, which can be used to calculate the area of the bed.

Line Delineation

In some cases kelp may form continuous strips along the shoreline, or appear to form a line. When less than 5m in width these strips should be recorded as lines, with a single series of waypoints taken at intervals of 5-10m, or where the line curves. A separation of greater than 8m between bulbs will mark the end of the current line and the beginning of a new form. Use the data sheets to mark the waypoints that correspond to the beginning and end of each line.

Points

Where time and resources allow, solitary bulbs or small clusters can be marked as points, by recording a single waypoint. In keeping with the above guidelines for delineation of lines and polygons, solitary bulbs or small clusters will be considered on their own when they are separated from other bulbs by more than 8m. Clusters should be marked with a single waypoint unless they are greater than 5m across in which case it will be marked as a bed.

Depths

A weighted measuring tape can be used to record depths along both the inside (shore-side) and outside (offshore) edges of kelp beds. For small beds it will suffice to take two depth measurements on the inside edge and two on the outside edge. Large beds will require more measurements. Let the weighted end of the tape drop until it reaches the bottom, wind it up slightly, and then lower it until to point where it begins to slacken. Record the exact time of each depth measurement, so as to account for the tide height and obtain an absolute depth. Again, minute-by-minute tide information can be obtained from many sources, including http://tbone.biol.sc.edu/tide/sites_othernorth.html.

Photos

Photos can be used as a visual reference of the size of kelp beds. Each bed mapped should be photographed above the surface, and a waypoint should be recorded at the location from which the photo was taken, with notes describing the location and direction of the camera. This can provide a visual reference not only of the location and areal extent but also the density of kelp beds.

Temperature

Ocean surface temperature data, collected over multiple years of monitoring, may provide helpful insight into year-to-year fluctuations in kelp abundance and distribution, and thus it is a useful indicator of environmental conditions affecting kelp. Kelp beds have been shown to fluctuate along with cyclical changes in sea surface temperature. Throughout el Niño cycles sea surface temperature also covaries[3] with other conditions such as storm activity and upwelling which impact kelp abundance. Data on sea surface temperature could provide insight into patterns of natural fluctuations in kelp abundance in relation to cyclical changes in climatic and environmental conditions. Temperature can be recorded with a temperature logger attached to a bouy, but it also may be available from nearby government observation stations.

[3] Fluctuates in tandem with another factor(s).

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Appendix 1 - Equipment List

Kayaks and associated equipment:
- life jackets
- whistles
- paddles (and spare)
- spray skirts
- pumps
- paddle floats
- safety lines
- VHF Marine Radio

GPS units (1 per mapper)
Waterproof covers for GPS units
Clipboard with lanyard and karabiner to attach to kayak
Data sheets – both kelp bed delineation sheet and metadata sheet
Measuring tape weighted at 0m mark

Appendix 2 - Safety Considerations

It is important to be aware of the currents in any area before beginning mapping activities. Current charts are often readily available and provide information for major passages, as well as adjustment calculations for adjacent passages. Weather warnings should also be checked for prior to launching kayaks, and kayakers should be trained in wet-exit and re-entry. Be sure to notify someone on land of your intended route and report back at a predetermined time.

Appendix 3 - Project Plan

The first step to beginning a mapping project is to gather background information and to review tide tables to select the best days for fieldwork. Have a clear idea of the extent of shoreline you plan to map, and identify areas that might be troublesome. These will include areas where currents reach high speeds, or where there is a high volume of boat traffic or ferries. Your mapping schedule can be planned to make the best use of the times that offer the most favourable conditions for these difficult areas.

Appendix 4 - Field Day Outline

1. Before launching, ensure all the necessary equipment from the equipment list (Appendix) has been prepared.

2. Record data from one hour before low tide until one hour after low tide, when the entire two-hour window has a tide height of 1.2m or less.

3. Paddle along the shoreline, scanning for kelp bulbs at the surface. When kelp is encountered determine whether it will be marked as a polygon, line, or point.
    a) Polygon – BedsMark waypoints along the edge of the bed, every 5-10m or where the edge changes direction, until a complete polygon has been delineated. Continuity of a bed is determined by a gap of 8m or less between bulbs. A separate bed is recorded if there is a gap of more than 8m or if the mapper determines that two beds are distinct.
    b) Lines – Lines are recorded if kelp is continuous in a particular direction, but the width of the visible area is 5m or less (if width is greater than 5m it will be considered a bed). Note the waypoints that mark the beginning and end of a line. Continuity of a line is determined using the same criteria as beds.
    c) Clusters – A group of kelp bulbs within 5m of each other in any direction is marked as a cluster.
    d) Points – A single kelp bulb at a distance of more than 8m from other bulbs is marked on its own as a point.

4. For each waypoint, record on the data sheet the waypoint number, depth if it is measured, time if necessary, and other notes. Notes should include whether the waypoint is part of a bed outline, a line, a cluster, or a point. Other observations may also be helpful, such as whether bulbs are dense or sparse.

5. Take photos of each bed so as to provide a visual reference, and record the photo numbers in the notes of the waypoint to which they pertain.

6. Take depth measurements along both the inside and outside edges of each bed using the weighted tape. 4 depth measurements for small to medium-size beds, and more for larger beds. Occasional depth measurements should be recorded along a line as well if possible.

Appendix 5 – Field Data Sheets

The following data sheets should be printed on waterproof paper, as regular paper will inevitably get wet and become useless for reading or writing, the two most important things you will want to do with it. They can be put on the clipboards, which can be attached to the kayak with a lanyard to prevent data loss should the clipboard fall overboard.